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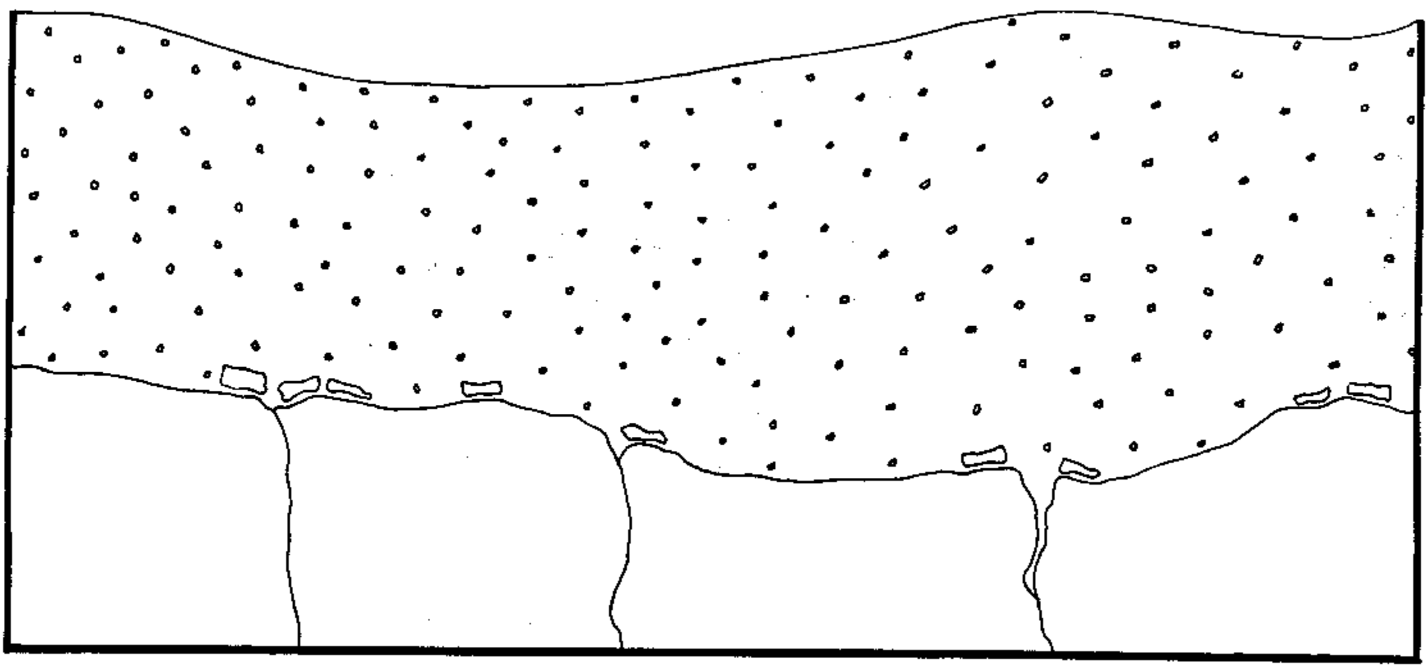

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With the increasing demand on natural resources such as land and water, the decreasing availability of low cost energy sources and the accelerated effort to preserve the quality of our surroundings, new techniques have been developed that allow more efficient use of our land, water and energy.

Computers have made possible the development of irrigation scheduling programs. Soil, water and salt movement models have been developed. New technology for irrigating agricultural land with food processing plant waste and municipal waste has been developed. It provides alternatives to dumping these wastes into streans and at the same time, conserves the fertilizer elements previously lost.

Most of the reactions in waste water renovation by land application are either dependent on time or on soil moisture content. A greater knowledge of soil properties is needed to use these new techniques. Values for hydraulic conductivity, matric potential, moisture retention times and soil moisture content relationships must be known.

Satisfactory methods are available for predicting vertical hydraulic conductivity under field conditions from saturated hydraulic conductivity and 0, -0.2, and -5.0 bar soil moisture contents determined on undistributed soil cores (2, 5, 9, 11, 12). However, these data are not readily available for most soils, because of the difficulty and expense of obtaining undisturbed samples at depths greater than 0.3 to 0.5 m.

Nielsen et al. (12) have criticized scientists and engineers for not accepting L.A. Richard's change to physically characterize water retention and conductivity in soils. They suggest that such information is necessary to improve soil and water management as well as to improve the quality of rural and urban life.

This bulletin brings together some physical and hydraulic data for the silt loam soils of southern Idaho that support a major portion of the agriculture in the Snake River Plain. Using the scientific techniques that are available and the data presented here, the computer modeler, irrigation water use planner or the land waste disposal planner can better predict what to expect from the soils of this region in terms of water availability, moisture movement rates and retention times at various soil moisture contents or matric potentials.

Silt Loam Soils of Southern Idaho

The predominant soils of the productive Snake River Plain section of the Columbia Plateau are wind-deposited, silt loams overlying irregular basalt flows (7). The Snake River Plain is from 850 to 1450 m (2800 to 4800 feet) above sea level with a 100- to 170-day growing season. Most of the area receives less than 300 mm (12 inches) precipitation per year.

The Portneuf, Minidoka and Kimama series and the Portino-Portneuf, Minidoka-Portneuf, Portneuf-Kimama and Portneuf-Portino-Trevion associations are characteristic of the southern Idaho silt loam soils. They generally have irregular topography and depth due to the underlying basalt lava flows. The fractured basalt bedrock provides good drainage under natural conditions; however, with the introduction of irrigation water to these soils, isolated wet spots develop that have to be artificially drained (3).

These highly productive surface soils are underlain by a hard layer. The depth, thickness and hardness of this layer are highly variable over small areas, a factor that is one of the diagnostic characteristics used in soil series classification. For example, the Minidoka series is described as having an indurated hardpan cemented with lime and silica, and the Portneuf as having a slightly hard silt loam layer. No mention of a restrictive layer is made in the Kimama series description (7).

Materials and Methods

Undisturbed soil core samples were taken from silt loam profiles at 3 locations with the Snake River undisturbed soil core sampler (8). Complete profile samples were taken at 4 points down to the basalt bedrock at each location. Duplicate surface-to-0.3 m (1 foot) core samples were taken from recently harvested pea, corn, bean and small grain fields and 4 surface-to-0.3 m (1 foot) core samples were taken from land that had never been cropped or irrigated. The core samples were placed in heat-shrinkable polyolefin tubing that was shrunk around the samples before they were taken to the laboratory for saturated hydraulic conductivity measurements.

Disturbed soil samples from corresponding depths were taken at each location for partial size distribution determinations by a hydrometer method (1).

The undisturbed soil core samples were supported in the polyolefin tubing while the saturated hydraulic conductivities were determined using the relationship:

$$K_s = \frac{V \Delta L}{A \Delta h \Delta t} \qquad (1)$$

where V is the volume of water passing between manometers a distance ΔL apart, divided by the cross-sectional area A and the hydraulic head difference in the manometers Δh, over time Δt.

After K_s was determined, the core samples were allowed to dry to about 15% moisture by volume and were cut into 20 mm (0.8 in) sections with a band saw, producing two samples between each manometer pair. Sawing the cores at this moisture content did not appear to change the physical characteristics of the samples. Volumetric moisture content was determined at 0.0, -0.2 and -5.0 bars matric potential on a ceramic pressure plate. Bulk density was also determined on these sample sections.

Moisture release curves were obtained for the core sections by expanding the equation of Cary and Hayden (5) to cover the soil matric potential range 0.0 to -5.0 bars and calculating the soil moisture-matric potential relationships for the samples. The expanded relationship is:

$$\Theta = a \exp(-b\tau) + (\Theta_5 + 5.0 - \tau) \qquad (2)$$

Where Θ is volumetric water content and τ is the matric potential in bars. The constants a and b are evaluated at $\tau = 0$ and 0.2, such that:

$$a = (\Theta_o - \Theta_5 - 5) \qquad (3)$$

and

$$b = 15 \log_{10} [a(\Theta_{0.2} - \Theta_5 - 4.8)^{-1}] \qquad (4)$$

The water content Θ_o, $\Theta_{0.2}$ and Θ_5 are the equilibrium values with pressure plate potentials of 0, -0.2 and -5.0 bars respectively.

Using the moisture retention curves thus obtained and the saturated hydraulic conductivity data from the same samples, hydraulic conductivity vs. water content curves were calculated using Jackson's equation (9) with a matching factor p = 1:

$$K_i = K_s \left[\frac{\Theta_i}{\Theta_s}\right]^p \frac{\sum_{j=1}^{m} [(2j+1-2i)\ \tau_j^{-2}]}{\sum_{j-1}^{m} [(2j-1)\ \tau_j^{-2}]} \qquad (5)$$

where K_i is the hydraulic conductivity (mm/h) corresponding to the i^{th} water content increment Θ_i, K_s is the saturated hydraulic conductivity. Θ_s is the saturated volumetric water content, and τ_j is the matric potential at the midpoint of each increment. The water content increments (Θ_i) were at 0.02 bar intervals covering the range 0 to -5.0 bars tension.

To test the predictive ability and to check for proper programming of equation 5, the values calculated here for silt loam surface soils were compared with measured values obtained by Cary (4) in Fig. 1. Also included in Fig. 1 are calculated and measured values for a Yolo loam (10). The agreement between the calculated and measured values suggests that the equation was properly used.

Results

Undisturbed soil cores and disturbed soil samples were taken from silt loam profiles that ranged in depth from 2 to 5.5 m (7 to 18 feet). All profiles of the Snake River Plain are not this deep however, and in many areas basalt lava flows are exposed at the surface. No samples were taken from profiles that had the lime and silica cemented indurated hardpan associated with the Minidoka series.

The results shown in Table 1 were divided to correspond as closely as possible with the natural horizons, showing the Ap or A horizon as about 0.2 m (0.8 feet); B plus Clca at 0.2 to 0.7 m (0.8 to 2.3 feet); C2ca at 0.7 to 1.2 m (2.4 to 4 feet); C3 below 1.2 m (4 feet). Below the C3 horizon the profile was divided into 0.3 m (1 foot) increments for sampling.

For the remaining discussion and figures the profiles were divided into the surface soil (0-0.2 m), the hard layer (0.2-1.5 m), the substratum (1.5 m to 0.6 m above basalt) and the caliche layer (the 0.6 m

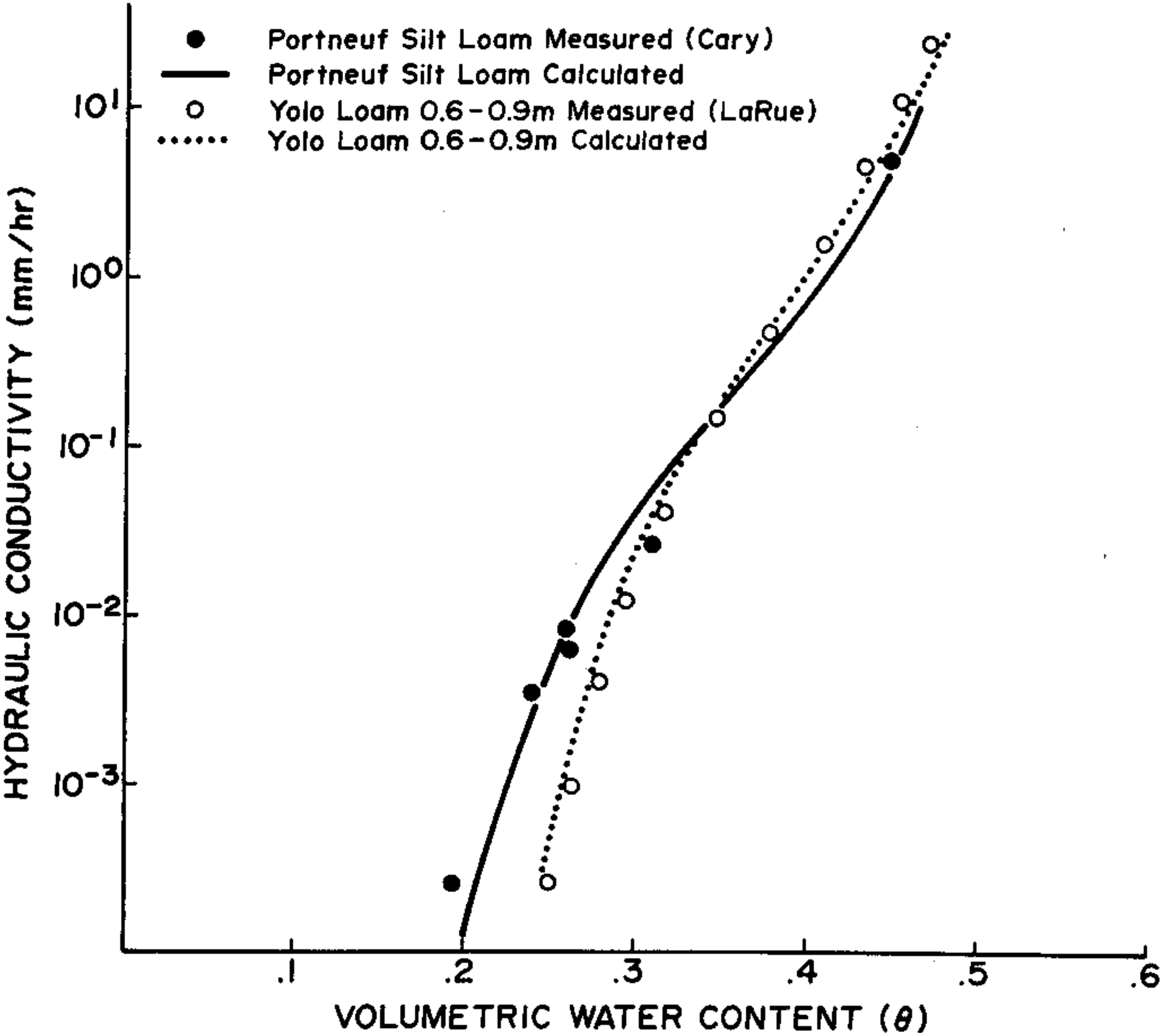

Fig. 1. Calculated and measured hydraulic conductivity values for a Portneuf silt loam and a Yolo loam.

above basalt). The samples taken between the basalt bedrock and 0.6 m above it were grouped separately regardless of depth because of their unique characteristics. No samples were taken where this caliche layer was less than 1.5 m (5 feet) below the surface.

Table 1. Bulk density and saturated hydraulic conductivity (K_s) with depth in silt loam soils.

Depth (m)	Bulk Density (g/cm^3)	K_s (mm/h)
0- .2	1.31 ± .06	9.8 ± 4.0
.2- .7	1.47 ± .16	10.5 ± 9.0
.7- .9	1.44 ± .12	12.0 ± 10.4
.9-1.2	1.32 ± .08	10.8 ± 7.8
1.2-1.5	1.32 ± .05	12.0 ± 6.3
1.5-1.8	1.32 ± .03	17.8 ± 3.4
1.8-2.1	1.31 ± .04	18.2 ± 3.0
2.1-2.4	1.30 ± .05	19.3 ± 3.1
2.4-2.7	1.34 ± .03	21.8 ± 2.7
2.7-3.0	1.28 ± .06	23.0 ± 2.8
3.0-3.3	1.27 ± .05	21.4 ± 2.4
3.3-3.6	1.26 ± .04	22.6 ± 2.1
3.6-3.9	1.31 ± .05	22.0 ± 2.0
3.9-4.2	1.34 ± .06	21.3 ± 2.7
4.2-4.5	1.30 ± .10	22.1 ± 3.2
Above Basalt		
0.6-0.3	1.48 ± .05	12.5 ± 4.3
0.3- Basalt	1.57 ± .06	10.3 ± 3.6

Bulk density and saturated hydraulic conductivity means are shown in Table 1 with their accompanying standard deviation, the greatest variation occurring in the the hard layer depths. Each bulk density mean represents from 60 samples in the upper layers to as few as 10 samples in the layers just above the caliche horizon.

Included in the surface soils are samples from cropland that had been irrigated for about 70 years and had recently produced peas, corn, beans or small grains, or had been irrigated but fallowed for 2 years. There are also samples from two previously nonfarmed areas. One of these had not been disturbed or irrigated, the other had been irrigated for 2 years and cultivated to keep weeds and grass from growing. The past histories did not influence bulk density or saturated hydraulic conductivity.

Particle size distribution versus depth is shown in Fig. 2. The solid linê represents the mean and the dotted lines represent the standard deviation. The curves are the result of 12 samples at each depth down to 1.5 m and 4 samples at each depth down to the basalt. The greatest textural variation occurs in the hard layer. The caliche is the only area where a texture other than silt loam exists.

Moisture retention curves (Appendix A) were developed for each of the 4 zones using the equation developed by Cary & Hayden (5). Here again the moisture release curves seemed to be unaffected by past cropping history. Cary and Hayden came to the same conclusion in a study designed specifically to determine the influence of cropping history on pore size distribution and hardness (6).

The relationship between hydraulic conductivity and water content was calculated for the 4 zones (Fig. 3). This was done using the means from moisture retension curves (Appendix A) and the saturated hydraulic conductivity data. The matric potential is shown on the curves at -0.1, -0.2, -1.0, and -5.0 bars. Tabular data for these calculations are given in Appendix B.

The hydraulic conductivity in the hard layer varied greatly as did the other characteristics of this zone, even though the hydraulic conductivity mean for the hard layer is quite similar to the means for other zones. Four hard layer samples (Fig. 4) all taken between 0.6 and 0.9 m (2 and 3 feet) over a small area were selected to show the highly variable hydraulic conductivities and matric potentials at any selected water content. Most of the samples did not show this much variation, however (see Appendix B).

Field observations by the author and others indicate that in general the hard layer does not restrice downward movement of water but there are small areas in some fields that do indicate limited water conductivity under irrigated conditions. The extreme variation of some of these samples could account for small, isolated areas that have low water conductivity rates.

Conclusions and Recommendations

Hydraulic conductivity, bulk density and moisture retention characteristics of the silt loam surface soils were not affected by cropping histories. These properties varied greatly in the hard layer, less in the substratum and the caliche layers. The mean hydraulic conductivity at matric potentials below —0.1 bar increased with depth to the caliche layer and then decreased to the basalt. There are small areas, however, where the hydraulic conductivity of the hard layers is lower than that of the surface soils.

The data presented here can be used in irrigation scheduling programs and in dryland area studies and management practice choices. Soil moisture status can be determined from gravimetric water content samples that are converted to volumetric water content — multiply by the soil bulk density. Then the matric potential (τ) and saturated hydraulic conductivity (K) can be read from Appendix B or taken from the appropriate figures. Water availability

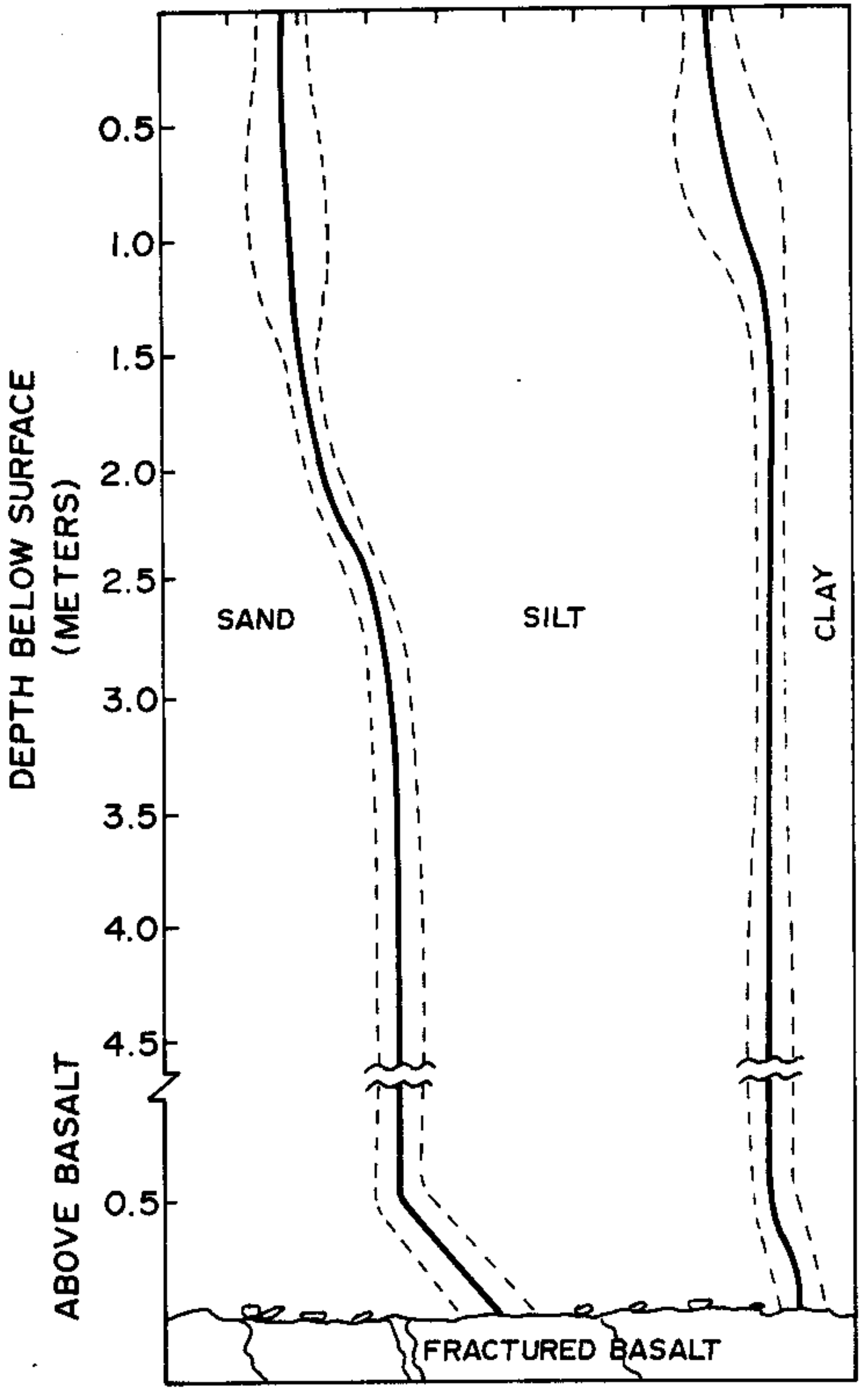

Fig. 2. Relative amounts of sand, silt and clay in the profiles sampled.

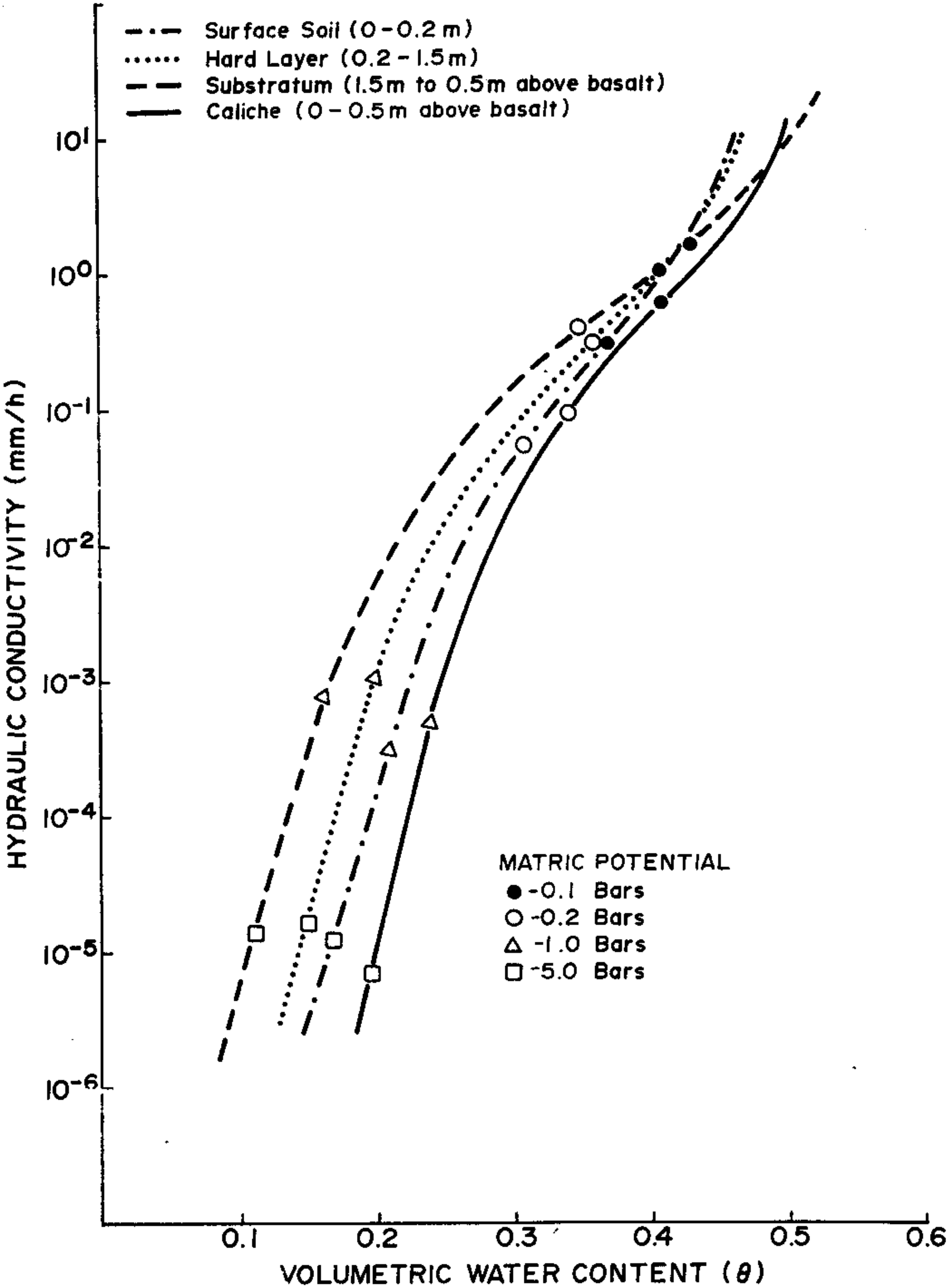

Fig. 3. Hydraulic conductivity - matric potential - water content relationships for the four zones in southern Idaho's silt loam soils.

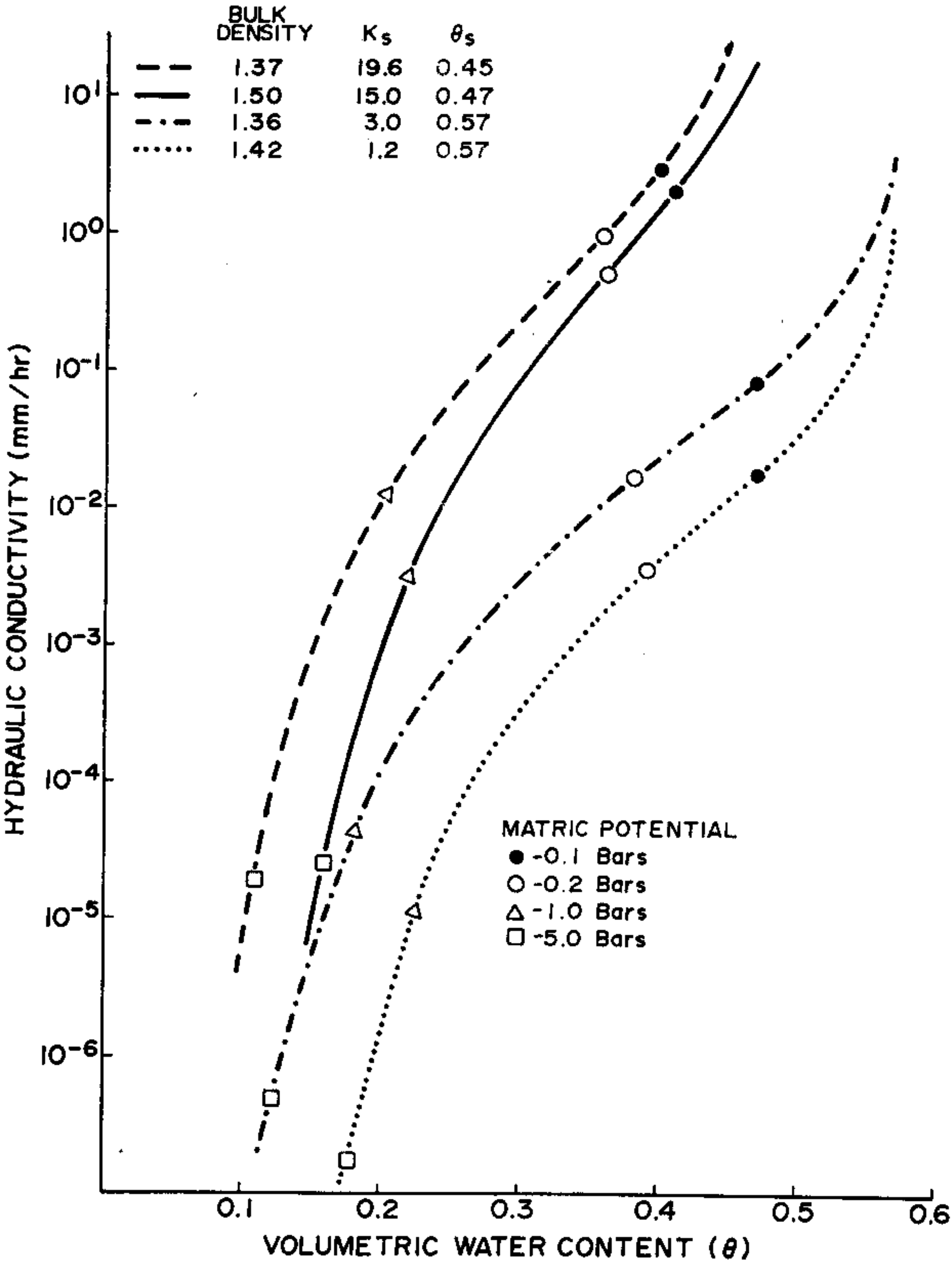

Fig. 4. Examples of hydraulic conductivity, water content and matric potential variation in the silt loam hard layer.

to the crop can be immediately determined from τ. Water loss rate by percolation can be determined from K. Using K and the evapotranspiration from the crop grown, the present as well as future water status can be estimated. Soils should be sampled in the drainage phase to avoid hysteresis effects.

Many of the reactions of waste water renovation by land application are time dependent. Soluble organic phosphates must be hydrolyzed to orthophosphates before they can be immobilized by precipitation or fixation in the soil. Nitrates need to be held in the root zone in order to be used by plants. Heavy metals are tied up by the soil. All of these reactions take a finite amount of time. Also, adverse reactions can occur if water is applied faster than it will move into and through the soil. Reducing conditions in the soil can dissolve iron and manganese and make the groundwater unfit for many uses. If the soil hydraulic conductivity characteristics are available, the land waste disposal planner can avoid many of the potential problems caused by overloading the disposal site and, at the same time, use only the needed land area for a given amount of waste water.

The rates of water flow away from septic tank drainfields, below lagoons and away from manure and waste water holding ponds can also be calculated from these data. Unit hydraulic conductivity and soil water diffusivity can also be calculated for the moisture range 0.0 to -5.0 bars on these silt loam soils, if areas affected by sodium or underlain by impervious layers do not exist.

State and federal agencies that make land use recommendations should obtain these kinds of data for a wider range of the predominant soil types of Idaho.

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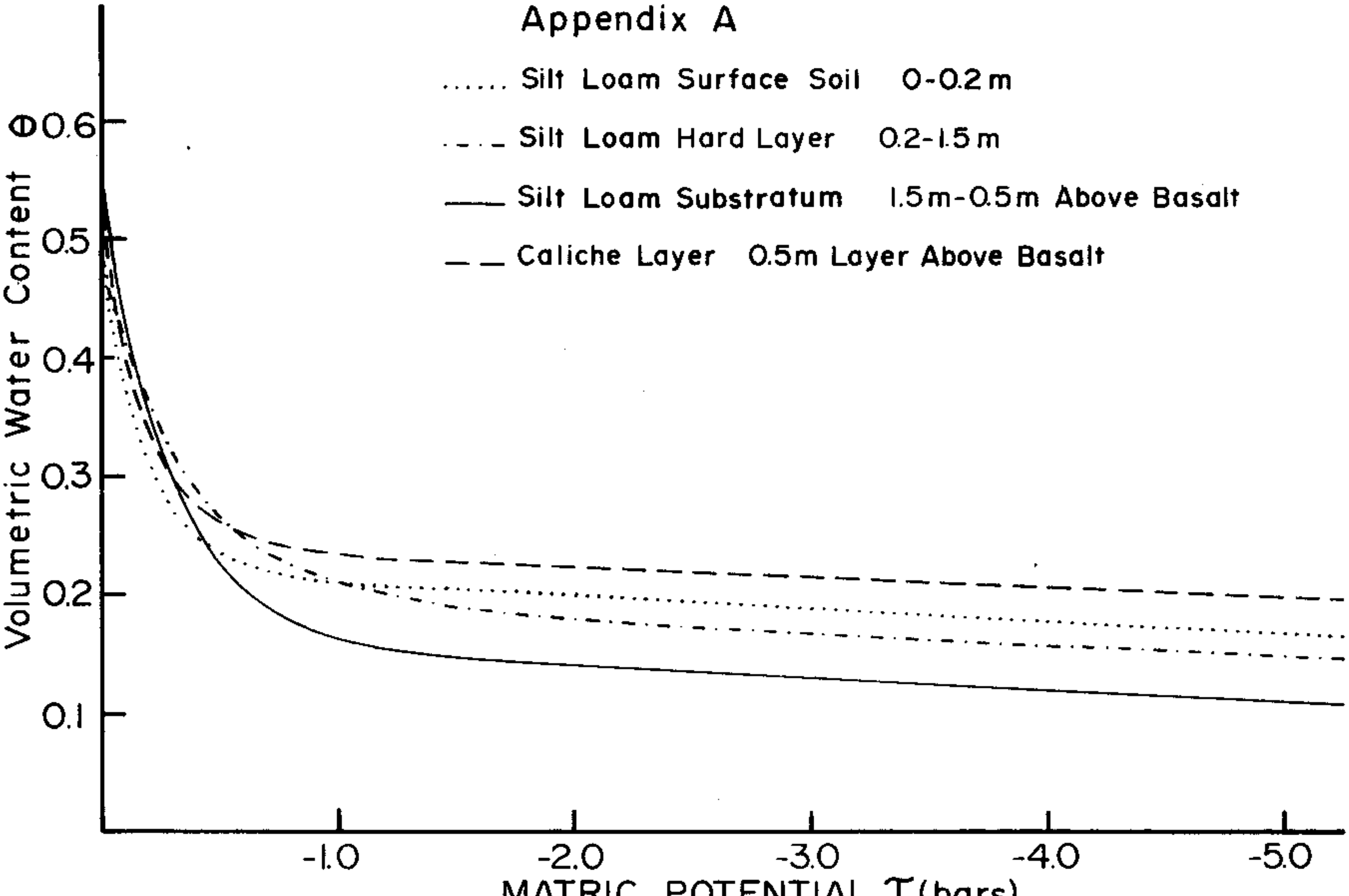
Appendix A
Silt Loam Surface Soil 0-0.2 m
Silt Loam Hard Layer 0.2-1.5 m
Silt Loam Substratum 1.5 m-0.5 m Above Basalt
Caliche Layer 0.5 m Layer Above Basalt
Volumetric Water Content Θ
0.6
0.5
0.4
0.3
0.2
0.1
-1.0
-2.0
-3.0
-4.0
-5.0
MATRIC POTENTIAL, Τ (bars)

APPENDIX B

Silt loam surface soil	0-0.2 m
Saturated hydraulic conductivity (K_s)	10.0 mm/hr
Saturated volumetric water content (Θ_s)	0.47
Approximate standard deviation of K	10%

Θ	τ (bars)	K (mm/hr)	Log K
0.46	-0.01	9.79	0.991
0.44	-0.02	3.19	0.504
0.42	-0.04	1.38	0.140
0.40	-0.06	0.73	-0.148
0.38	-0.09	0.41	-0.385
0.36	-0.12	0.24	-0.618
0.34	-0.15	0.14	-0.855
0.32	-0.18	0.077	-1.100
0.30	-0.22	0.040	-1.391
0.28	-0.27	0.019	-1.710
0.26	-0.33	0.0081	-2.090
0.24	-0.44	0.0027	-2.566
0.22	-0.67	0.00065	-3.186
0.20	-1.88	0.00011	-3.956
0.18	-3.90	0.000029	-4.541
0.16	-6.00	0.000007	-5.129

Silt loam hard layer	0.2-1.5 m
Saturated hydraulic conductivity (K_s)	10.0 mm/hr
Saturated volumetric water content (Θ_s)	0.48
Approximate standard deviation of K	85%

Θ	τ (bars)	K (mm/hr)	Log K
0.47	-0.02	9.79	0.991
0.45	-0.04	3.97	0.598
0.43	-0.06	1.99	0.298
0.41	-0.10	1.10	0.043
0.39	-0.14	0.67	-0.177
0.37	-0.17	0.41	-0.390
0.35	-0.22	0.28	-0.606
0.33	-0.28	0.15	-0.825
0.31	-0.33	0.088	-1.056
0.29	-0.38	0.049	-1.311
0.27	-0.46	0.025	-1.596
0.25	-0.58	0.012	-1.917
0.23	-0.71	0.0051	-2.290
0.21	-0.95	0.0018	-2.744
0.19	-1.45	0.00050	-3.305
0.17	-2.90	0.00010	-3.983
0.15	-4.90	0.000016	-4.805

Silt loam substratum	1.5 m-0.5 m above basalt
Saturated hydraulic conductivity (K_s)	21.0 mm/h
Saturated volumetric water content (Θ_s)	0.53
Approximate standard deviation of K	10%

Θ	τ (bars)	K (mm/hr)	Log K
0.52	-0.01	20.6	1.314
0.50	-0.03	7.4	0.869
0.48	-0.05	4.3	0.643
0.46	-0.07	2.8	0.451
0.44	-0.09	1.8	0.275
0.42	-0.12	1.3	0.116
0.40	-0.14	0.91	-0.040
0.38	-0.16	0.63	-0.202
0.36	-0.18	0.42	-0.371
0.34	-0.21	0.28	-0.548
0.32	-0.24	0.18	-0.734
0.30	-0.28	0.11	-0.934
0.28	-0.32	0.071	-1.148
0.26	-0.38	0.042	-1.381
0.24	-0.44	0.023	-1.639
0.22	-0.50	0.012	-1.933
0.20	-0.60	0.0052	-2.282
0.18	-0.75	0.0020	-2.706
0.16	-1.05	0.00058	-3.237
0.14	-2.10	0.00013	-3.873
0.12	-4.00	0.000030	-4.519
0.10	-6.00	0.000005	-5.319

Caliche layer above basalt	0.5 m thick
Saturated hydraulic conductivity (K_s)	12.5 mm/h
Saturated volumetric water content (Θ_s)	0.51
Approximate standard deviation of K	15%

Θ	τ (bars)	K (mm/hr)	Log K
0.50	-0.01	12.2	1.088
0.48	-0.03	4.0	0.597
0.46	-0.05	2.2	0.338
0.44	-0.07	1.3	0.115
0.42	-0.09	0.80	-0.099
0.40	-0.11	0.48	-0.319
0.38	-0.13	0.28	-0.550
0.36	-0.17	0.16	-0.794
0.34	-0.20	0.088	-1.055
0.32	-0.25	0.045	-1.348
0.30	-0.30	0.021	-1.685
0.28	-0.38	0.0080	-2.095
0.26	-0.52	0.0024	-2.620
0.24	-0.95	0.00048	-3.318
0.22	-2.70	0.000068	-4.165
0.20	-4.75	0.000010	-4.991